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APPLICATION OF LANDSAT DATA TO DELIMITATION OF
AVALANCHE HAZARDS IN MONTANE COLORADO

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PREFACE

Over the last several years, the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado has been involved in the delineation, mapping, and analysis of natural hazards in selected portions of the Colorado Rocky Mountains. Much of this research has been concerned with the detailed delineation of snow avalanche hazards using air photo and field mapping techniques. Continuous monitoring of various environmental parameters during the winter avalanche cycle has produced significant advances in the field of avalanche prediction and forecasting for local areas.

In June 1975, INSTAAR began research for the National Aeronautics and Space Administration (NASA contract NAS5-20914) on a new approach to avalanche hazard investigation. The purpose of this research is to analyze, evaluate, and apply LANDSAT imagery for delineating and mapping avalanche hazards in the Colorado mountains. Research is currently being directed toward six primary objectives:

- (1) Compilation and analysis of historical avalanche records for cause/effect and frequency information.
- (2) Identification of avalanche hazard terrain characteristics detectable on LANDSAT imagery.
- (3) Determination of relative usefulness of LANDSAT imagery for avalanche hazard mapping.
- (4) Determination of useful schemes for cartographically representing avalanche hazards.
- (5) Using the synoptic and repetitive aspects of LANDSAT imagery for regional avalanche hazard mapping and analysis.
- (6) Examining the cost/benefits of avalanche hazard investigations.

Secondary, and purely experimental, objectives of the research project are as follows:

- (1) Investigation of potential usefulness of LANDSAT derived information as input to avalanche forecast or warning systems.
- (2) Investigation of the usefulness of LANDSAT imagery for mapping major landslide areas.

During the report period (1 September - 30 November), research was conducted by two INSTAAR research staff members; an additional graduate research assistant will be working on the project during the next report period. Research conducted during this report period has shown that:

- (1) direct avalanche indicators cannot be consistently interpreted from single-band, black and white LANDSAT imagery because of terrain shadows, low resolution, and other considerations;
- (2) a satisfactory evaluation of the potential for avalanches can be interpreted from stereoscopic LANDSAT imagery by analyzing topographic factors including slope angle, aspect, and profile and relief (indirect indicators);
- (3) a mapping scheme that shows avalanche potential graded as to size of the largest avalanche expected results in a more uniformly reliable and easily interpretable map than does attempts to show individual avalanche paths that cannot be consistently identified;
- (4) an alternative method must be found to allow topographic analysis to be conducted in those areas for which stereoscopic LANDSAT coverage is not available. Possible methods include (a) computer-generated LANDSAT stereopairs, (b) small-scale aircraft photography, and (c) improving capability for monoscopic LANDSAT imagery interpretation;
- (5) further attempts to identify direct avalanche indicators should be made using color enhanced and color composite LANDSAT imagery.

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INTRODUCTION

This report summarizes the work conducted by the Institute of Arctic and Alpine Research (INSTAAR), University of Colorado, during the period 1 September - 30 November 1975, under contract NAS5-20914 to the National Aeronautics and Space Administration/Goddard Space Flight Center.

During the report period, further study was given to the ability of a photointerpreter to identify direct and indirect avalanche indicators on black and white, single-band LANDSAT imagery. Regional avalanche mapping was expanded to include the eastern San Juan Mountains and a mapping scheme was developed that allows the avalanche potential of an area, rated according to the size of the largest avalanche expected, to be prepared from topographic analysis of single-band, black and white LANDSAT images.

HISTORICAL DATA

The task of documenting historical avalanche occurrences in the Colorado Rocky Mountains is proceeding slowly as time permits. Additional information is being supplied by other INSTAAR researchers not directly funded by the project. Of particular importance is the work of Mrs. Betsy Armstrong covering much of the San Juan Mountain area along U.S. 550. During the last few years, Mrs. Armstrong has done extensive library research and has interviewed numerous local residents for historical avalanche information. The results of this work is presently being put in manuscript form and will be provided to the project.

IDENTIFICATION CRITERIA

Accomplishments

To map avalanche hazards, it is necessary to be able to distinguish between areas subject to avalanching and areas in which avalanches do not occur. In addition, the size of potential avalanches and the probability that these avalanches will encounter people and property must be considered to effectively assess the degree of avalanche hazard.

During the first report period, the physical indicators of avalanche-prone areas, both direct and indirect indicators, were defined in some detail (1). During this report period, LANDSAT images of the central San Juan Mountains were studied to see which of the avalanche indicators are detectable on the imagery and to what degree these indicators can be identified using conventional photointerpretation techniques on the black and white, 1:1,000,000 positive transparencies, as well as photographic enlargements of these transparencies.

In general, direct avalanche indicators, including snow characteristics and vegetation patterns, cannot be consistently interpreted from the imagery. Evidence of avalanching contained in the distribution of snow (lingering patches of snow in runout zones and tracks on spring and early summer imagery) is generally too small to be identified, although a few instances have been noted. No evidence of dynamic snow movements have been detected on any of the consecutive-day images studied.

Vegetation anomalies characteristic of avalanche areas have likewise been difficult to identify with certainty. The largest and most dramatic vegetation anomaly associated avalanches, the trimline, was identified in

several areas, but other well-known trimlines could not be identified. The difficulty arises because of three factors: (1) trimlines are commonly on valley slopes and these slopes are often in shadow; many of the obvious linear tonal changes oriented downslope can be interpreted as either trimlines or shadow lines because the gray tonal contrasts are not distinctive; (2) many avalanche paths defined by sharp trimlines are too small to be adequately resolved on the imagery; (3) forest/non-forest boundaries resulting from other natural or artificial causes are easily mistaken for trimlines (the opposite also applies) because the image resolution is too poor for positive identification.

Better and more consistent results have been produced by evaluating the LANDSAT images for indirect indicators of avalanche-prone areas. Of these, topographic indicators including slope angle, slope aspect, slope profile, and relief seem to provide sufficient information for distinguishing between avalanche and non-avalanche areas in the central San Juan Mountains; comparisons between LANDSAT imagery analysis and detailed (1:24,000) avalanche hazard maps produced by INSTAAR personnel have been encouraging.

Topographic analysis of the LANDSAT images has, however, only been effective where stereoscopic interpretation can be performed using consecutive-day images. Without the stereoscopic model, interpretation is difficult and, in many instances, has been incorrect. Pseudostereoscopic analysis using two bands of the same scene for a stereopair does give a perception of the third dimension, but the vertical exaggeration is too slight to allow confident interpretation.

Problems

Failure to be able to identify direct avalanche hazard indicators

indicates that the monitoring of avalanche occurrences may not be possible using LANDSAT imagery. However, there is still the possibility that some vegetation patterns directly associated with avalanche paths will be identifiable on color enhanced imagery.

The major method of avalanche hazard identification using LANDSAT imagery must probably be based largely on topographic analysis, and there are significant portions of the state for which stereoscopic LANDSAT coverage is not presently available.

Next Report Period

During the next report period, research will be conducted along the following lines:

- (1) Evaluate the capability to identify direct avalanche indicators using color enhanced LANDSAT imagery.
- (2) Study the feasibility of using LANDSAT computer-generated stereo-pairs employing the method developed by R.M. Batson and E.M. Eliason (U.S. Geological Survey, Center of Astrogeology, Flagstaff, Arizona) (2).
- (3) Obtain and evaluate additional imagery for direct avalanche indicators.
- (4) Continue to compile catalogue of avalanche hazard indicators that are detectable on LANDSAT imagery.

AVALANCHE MAPPABILITY

Accomplishments

The inability to consistently identify and map direct avalanche hazard indicators casts some doubt on the potential application of LANDSAT imagery for avalanche hazard mapping. So, during this report period, avalanche hazard mapping was conducted using indirect (topographic) indicators as the main source of avalanche hazard information, with direct indicators supplementing the topographic interpretations where possible.

The resulting map shows the potential for avalanches in the mapped area graded as to size (none, small, medium, or large) of the largest avalanche that might be expected. Comparison of this mapping with detailed (1:24,000) avalanche hazard maps by other INSTAAR researchers shows that this method is (1) relatively accurate and (2) not greatly affected by shadows or inability to identify direct avalanche indicators.

Consequently, we feel that potential for avalanches can be evaluated from LANDSAT imagery on a generalized, regional scale, although semi-detailed site evaluation will probably not be possible except in rare cases.

As the ability to evaluate topography increases with additional experience and the capability to detect and identify direct avalanche indicators is improved using color enhanced imagery and other, perhaps better, imagery not yet studied, it is anticipated that our mapping project will be successfully completed on schedule.

Avalanche hazard maps prepared from LANDSAT imagery analysis on this project must meet certain criteria:

- (1) The maps must be understandable by persons not especially trained in

remote sensing or avalanche research;

- (2) They must depict the avalanche hazard information as completely and accurately as possible; and
- (3) They must be representative of the kind of information that is extractable from LANDSAT imagery.

During the first report period, the mapping scheme used attempted to show (a) individual avalanche paths, (b) areas of probable avalanching, and (c) areas of no avalanche potential. However, this scheme, we feel, is too easily misinterpreted because individual avalanche paths cannot be consistently interpreted from the imagery because of resolution, shadows, and other considerations. The result is that areas where individual paths could not be identified and shown on the map might be considered more safe than areas where the paths are mapped. This, of course, is not necessarily the case.

Therefore, a revised scheme is being developed to better depict the potential for avalanches in all areas on more equal terms. This scheme attempts to classify all areas according to the size of potential avalanches that might be expected in the area if conditions existed that would produce full-track avalanche runs; implicit in this classification is the fact that avalanches smaller than maximum could occur.

The size classification (Table 1) is based on the work of Frutiger (3) and is determined by the maximum area of potential starting zones or catchment basins that could conceivably release at one time.

Table 1. Classification of maximum potential full-track avalanche based on area of starting zone.

<u>Size</u>	<u>Area of Starting Zone</u>
Ø	None
Small	≤ 7 acres
Medium	7 to 30 acres
Large	> 30 acres

To determine the size of potential avalanches using the LANDSAT imagery, templates were constructed for 7 and 30 acre areas. Since the starting zones are sloping surfaces, the actual areas of the templates were adjusted to represent 7 and 30 acre areas on 45 degree average slopes. This is somewhat greater than average slope, but it was felt that it is better to overestimate the size of potential avalanches than underestimate them.

The area of the potential starting zone is first interpreted on the LANDSAT imagery and then it is compared to the templates, and the appropriate classification is made. The area of this classification is extended until the size of the largest potential avalanches changes. The resulting map, then, shows broad areas of similar avalanche characteristic maximum size. Within these areas, of course, are smaller areas where smaller avalanches can occur.

Although the method is not precise, it does provide a means for helping to isolate areas of large avalanches from those that will probably be of little concern. This is the first step at determining the hazard associated with various areas. Other factors we must now consider are (1) frequency of occurrence and (2) distribution of people and property, which

together provide the information for determining the avalanche hazard.

Next Report Period

During the next report period, the mappability of avalanche hazards will be further assessed by:

- (1) studying color enhanced imagery;
- (2) refining the mapping scheme to better fit the type of information that is extractable from LANDSAT imagery; and
- (3) studying new sets of LANDSAT imagery.

REGIONAL AVALANCHE MAPPING

Accomplishments

During the report period, preliminary potential avalanche maps have been prepared for much of the eastern (R. Summer) and western (D. Knepper) portions of the San Juan Mountains; a northeast-trending strip across the central San Juan Mountains has not yet been mapped due to lack of stereoscopic coverage. Qualitative, visual comparison of the LANDSAT-derived mapping in the western San Juan Mountains with detailed (1:24,000) avalanche maps of the region indicate that the quality of the LANDSAT mapping is quite satisfactory for the scale of the avalanche hazard mapping being done for this project.

Problems

The major problems encountered in the regional avalanche mapping is the lack of stereoscopic LANDSAT coverage in portions of the Colorado Rocky Mountains. We hope this problem can be overcome by (1) acquiring computer-generated LANDSAT stereopairs, (2) using high-altitude aircraft photography (1:100,000), or (3) improving our ability to do good LANDSAT interpretation using pseudo-stereoscopic or monoscopic analysis.

Next Report Period

R.M. Batson (U.S.G.S., Center of Astrogeology) has been contacted for details on the method of producing computer-generated LANDSAT stereopairs, and during the next report period we should find out whether the University of Colorado has the necessary hardware for using this method

and, if not, whether we might have this done commercially. In any event, we will attempt to acquire a computer-generated stereopair of a portion of the San Juan Mountains in order to evaluate the quality of the imagery for the purpose of avalanche mapping.

Regional avalanche mapping will be extended northward into new areas for which stereoscopic LANDSAT coverage is available. For those areas in which mapping is completed, preliminary avalanche hazard maps will be prepared and evaluated. It is anticipated that by June 1976 the avalanche mapping will be completed and preliminary avalanche hazard maps will be prepared for much of the area.

CARTOGRAPHIC REPRESENTATION

An avalanche hazard map should depict the following types of information in an easily interpretable manner:

- (1) Size of potential avalanches.
- (2) Probability of occurrence.
- (3) Distribution of people and property.

To date, we have been most concerned with mapping the distribution of potential avalanche areas of various sizes. This information is easy to show on maps by using colors or patterns or symbols to identify the size of potential avalanches in various areas (item 1 above).

However, the preparation of an avalanche hazard map incorporating all three types of information described above will be a much more difficult task. The method ultimately adopted will depend greatly on the type and amount of information for items (2) and (3) above that can be gathered. Two basic methods are now being considered:

- (1) A base map showing the distribution of avalanches of various sizes with separate overlays for items (2) and (3) above.
- (2) A single map showing contours representing degree of avalanche hazard determined by assigning values to each type of information (items 1, 2, and 3) for points on a grid and computing a combined value for each of these points that represents avalanche hazard.

These methods, and variations of these methods, will be investigated and refined during the remainder of the project.

SIGNIFICANT RESULTS

Photointerpretation of individual avalanche paths on single-band, black and white LANDSAT images is greatly hindered by terrain shadows and the low spacial resolution of the LANDSAT system. Maps produced in this way are biased towards the larger avalanche paths that are under the most favorable illumination conditions during imaging; other large avalanche paths, under less favorable illumination, are often not detectable and the smaller paths, even those defined by sharp trimlines, are only rarely identifiable.

PUBLICATIONS

No project-funded publications were prepared during the report period.

RECOMMENDATIONS

It would be advantageous to the project if we had a sample computer-generated LANDSAT stereopair of the San Juan Mountains, so that the quality of the processed imagery could be evaluated in terms of avalanche mapping. A letter requesting information on the technique has been sent to R.M. Batson (U.S. Geological Survey, Center of Astrology, Flagstaff, Arizona), but we have not yet had a reply. It is recommended that our technical monitor, Mr. James Broderick, assist us in obtaining a sample computer-generated stereopair as quickly as possible, so that the technique can be evaluated and either (a) adopted and pursued or (b) rejected and the search for an alternative method of extracting topographic information from LANDSAT imagery begun.

FUNDS EXPENDED

A total of \$11,733 has been spent on the project.

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